

The VLBA Calibrator Search for the BeSSeL Survey

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Abstract

We present the results of a survey of radio continuum sources near the Galactic plane using the Very Long Baseline Array (VLBA). Our observations are designed to identify compact extragalactic sources of milliarcsecond size that can be used for parallax measurements in the Bar and Spiral Structure Legacy Survey. We selected point sources from the NVSS and CORNISH catalogs with flux densities above 30 mJy and within 1.5° of known maser targets. Of the 1529 sources observed, 199 were detected. For sources detected on 3 or more baselines, we determined accurate positions and evaluated their quality as potential calibrators. Most of the 1330 sources that were not detected with the VLBA are probably of extragalactic origin.

Subject headings: Galaxy: general — HII regions — astrometry — surveys — radio continuum

1. Introduction

The Very Long Baseline Array (VLBA) calibrator search is a preparatory survey for the Bar and Spiral Structure Legacy (BeSSeL) survey (Brunthaler et al. 2011) which will study the spiral structure and kinematics of the Milky Way. The BeSSeL survey will determine distances, via trigonometric parallax, and proper motions for methanol and water masers at 6.7 and 22 GHz in several hundred high mass star forming regions in our Galaxy. These results will allow us to locate spiral arms and determine the 3-dimensional motions of massive, young stellar objects in the Galaxy. (for further information about the BeSSeL survey see <http://www.mpifr-bonn.mpg.de/staff/abrunthaler/BeSSeL/index.shtml>)

Currently the VLBA calibrator search list contains information on compact radio sources from the surveys of Ma et al. (1998); Beasley et al. (2002); Fomalont et al. (2003); Fey et al. (2004); Petrov et al. (2005, 2006, 2008); Kovalev et al. (2007). Recently Petrov et al. (2011) published the results of a survey of 489 calibrator sources close to water masers in the Galactic plane for the Japanese VLBI Exploration of Radio Astrometry¹ (VERA) project. However, a search for background sources near any given maser target with the VLBA calibrator search tool usually yields a source within about 3° on the sky. Since transferring interferometer phases over such a large angular distance often provides poor results, such background sources are not always preferable for accurate parallax measurements. Since systematic errors scale approximately linearly with the separation between target and calibrator source, it is valuable to find background sources as close to the target as possible.

This paper presents the results from our calibrator survey. While this survey was tailored for finding compact extragalactic sources for the BeSSeL parallax observations, it should also be useful for other VLBA observations. Also, the compact sources found in this survey should

¹<http://veraserver.mtk.nao.ac.jp/>

be useful for future EVLA and ALMA observations. Since, historically, there has been a shortage of good calibrators near the Galactic plane, this survey should be especially valuable for interferometric observations of Galactic sources.

2. Source Selection and Observation

Point-like sources from the NVSS (sizes $< 20''$) and CORNISH catalogs (provided by Condon et al. 1998; Purcell et al. 2008) with flux densities above 30 mJy and within circles with a radius of 1.5° around the 109 target maser sources formed the survey list. Since a Bessel parallax observation benefits from at least one calibrator with a milliarcsecond-accurate position, we added between 1 and 3 sources from the ICRF2² catalog (Fey et al. 2009) that were within 5° of each target maser position. Since some target masers were separated by less than 3° , a number of candidates were observed 2 or more times and the total areal coverage was ~ 600 square degrees. However, the calibrator survey is **not** complete to 30 mJy, since time restrictions typically allowed observing only the ≈ 25 most promising sources for each target position. Thus, in some search fields, a small number of the weaker and more distant sources were not observed.

In total, 1529 sources were selected for observations with the VLBA. Figure 1 shows the covered area of the survey in Galactic coordinates. The black dots mark the positions of the target masers, the black ellipses represent the circular area on the sky searched for calibrators. All sources were observed at X-band in left-circular polarization. We used eight 16-MHz bands, with band center frequencies spanning the range from 8109.49 to 8583.49 MHz. The bands were spaced in a minimum redundancy configuration to sample, as uniformly as possible, all frequency differences in order to minimize multi-band delay sidelobes. Each survey source was observed for three minutes. Three strong fringe-finders were observed at the beginning and the end of the

²International Celestial Reference Frame

typically five-hour tracks.

The data reduction was conducted with the National Radio Astronomy Observatory’s³ Astronomical Image Processing System, using the scripting software ParselTongue⁴ (Kettenis et al. 2006). In the first step, we corrected the data for the latest Earth Orientation Parameter (EOP) values. With the AIPS task TECOR, we derived corrections for the ionospheric Faraday rotation from maps of total electron content, which are available in the CDDIS⁵ data archive. Then, one scan on a strong fringe-finder was used to solve for single-band delays and to align the phases of all IFs. To remove clock offsets, mini-geodetic block sources were fringe fitted. Next, we determined multi-band delays and fringe-rates for the fringe-finder blocks placed at the beginning and end of the observations. We averaged these values for each block and removed their effects from the survey data. Afterwards, the residual multi-band delays and fringe rates for the candidate sources were modeled as owing to source position offsets and revised positions were determined by least-squares fitting. In addition, we generated plots of interferometer visibility amplitude versus the baseline length by vector averaging the data over each scan for each interferometer baseline in order to determine the source compactness.

3. Detections

199 candidate sources were detected on at least one VLBA baseline, of which 70 are sources of the ICRF2 catalog and 30 were previously detected by Petrov et al. (2011). Our goal was to determine reliable positions for the candidate calibrator sources. For 25 of the ICRF2 sources,

³The National Radio Astronomy Observatory (NRAO) is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

⁴<http://www.radionet-eu.org/rnwiki/ParselTongue>

⁵NASA’s Crustal Dynamics Data Interchange System

the ICRF2 catalog position was significantly better than our measured source position. For these sources, we replaced the source coordinates by an average of the measured and the ICRF2 coordinates.

Depending on a source’s compactness, a grade from A to D was assigned, representing their quality as a potential calibrator. Compactness was determined by examining the visibility plots by eye and estimating the maximum baseline length (in wavelength units) for which the normalized fringe visibility was greater than 0.2. For grade A sources, which are the most compact, the normalized fringe visibility falls below this threshold at $> 200 \text{ M}\lambda$. Grade B and C sources are defined to have normalized visibilities greater than 0.2 for baselines longer than 100 and 50 $\text{M}\lambda$, respectively. Grade D sources were more resolved than grade C sources, but still detected on 3 or more baselines. Finally, grade F sources were detected on only one or two baselines. The two shortest VLBA baselines have lengths of 236 km (PT–LA) and 417 km (KP–PT). Grade F sources were not used in the following statistical analysis.

Figure 2 shows examples of the visibility plots for sources of each grade, A through D. Since we could not reliably detect sources with correlated flux density $< 30 \text{ mJy}$, it was not always possible to measure weak sources $< 100 \text{ mJy}$ with a normalized fringe visibility of 0.2.

Due to overlapping observing fields around the target masers, some sources were observed multiple times. Since the observations took place at different times, the fitted coordinates, uncertainties, and assigned grades can differ among observations. For sources with grades A through D that were observed two or more times, we determined weighted means and standard deviations for the coordinates in Right Ascension and Declination. The formal position variances from the delay and rate fits served as the weights. To guard against unrealistically small variances, which can come from limited data, we established a lower limit of $0.003''$ for individual position uncertainties. We found the rms position deviations were generally larger than that expected from the formal position uncertainties, indicating the levels of systematic errors present in our

“snap-shot” VLBA observations.

While most sources that were observed multiple times had the same compactness grade, some borderline cases were found that had mixed grades. Therefore, we assigned numerical grades of 4 through 1 for grades A through D, and obtained an (unweighted) average source grade. The multiple observed sources were then placed in four groups according to their average grade. The grade A group contained all sources with numerical grades above 3.5, the grade B group between 2.5 and 3.5, the grade C group between 1.5 and 2.5, and the grade D group below 1.5. 17% of the observed ICRF2 sources have a bad grade (C or D).

Finally, we calculated the average of the individual position standard deviations for all sources in each group. In order to avoid the rare very poor measurement from biasing the average deviation, we discarded individual sources with position standard deviations exceeding 50 mas. The average standard deviations (global grade errors) serve as empirical indications of true source position uncertainties and are summarized in Table 1.

The empirically determined position errors for each grade were then used as an “error floor” for the position errors reported in Table 2. Since, in this first-pass processing potentially unreliable formal errors were used for weighting, we recalculated the mean coordinates and the standard errors of the mean with data weights formed from the geometric mean of the formal fitting errors and the error floors for the appropriate source grade. For the 30 sources in common with the Petrov et al. (2011) survey, their positions agree within the joint uncertainties. A comparison with the ICRF2 catalog is not meaningful for the 25 sources whose positions have been improved by averaging the measured and the ICRF2 coordinates. The coordinates of the remaining 45 ICRF2 sources coincide with the ICRF2 catalog positions within the joint uncertainties.

Table 2 lists all detected sources together with the estimated coordinates (Column 2,3), position uncertainties (Column 4,5), grades (Column 6), fluxes (Column 7), and the number of observations (Column 8). This table also contains the grade F sources for which the coordinates

come from the NVSS catalog. The histogram in Fig. 3 shows the distribution of the sources over the four grade groups.

4. Non-Detections

A total of 1330 objects were not detected with the VLBA. Their coordinates, position uncertainties, and flux densities are extracted from the NVSS and CORNISH point source catalogs (see Table 3, the entire table will be published in the online version). The non-detected sources could be galactic (e.g. HII regions, SNRs) or extragalactic (e.g. lobes of radio sources). A comparison with catalogs of Galactic HII regions (Kuchar & Clark 1997; Paladini et al. 2003; Quireza et al. 2006) yields less than 50 possible identifications. In order to determine if the remaining objects are likely extragalactic, we estimated the number of detectable extragalactic sources from extragalactic source counts. Since most of the non-detected sources were selected from the NVSS catalog at 1.4 GHz, we used a normalized differential source count at this frequency provided by Condon (1984). Since most of the sources in our non-detection list have flux densities above ~ 50 mJy, we chose this value as a lower limit for the source count calculations. Integrating the source number function as a function of flux density from 50 mJy to ~ 1 Jy yields a predicted value of ~ 12000 radio sources per steradian. Since our survey covered an area of ≈ 600 square degrees, one would have expected ~ 1300 detections, which is consistent with our observations. Thus, we assume that most of the non-detected sources are extragalactic.

5. Concluding Remarks

In this paper, we present the results of a calibrator search for the BeSSeL survey. Of the 1529 radio continuum sources observed, 199 candidate calibrator sources were detected. Most of the 1330 undetected sources are probably of extragalactic origin. The list of calibrator candidates will

be made available on the homepage of the BeSSeL survey. Furthermore, the ALMA and EVLA communities can use this list as a starting point for their own calibrator surveys.

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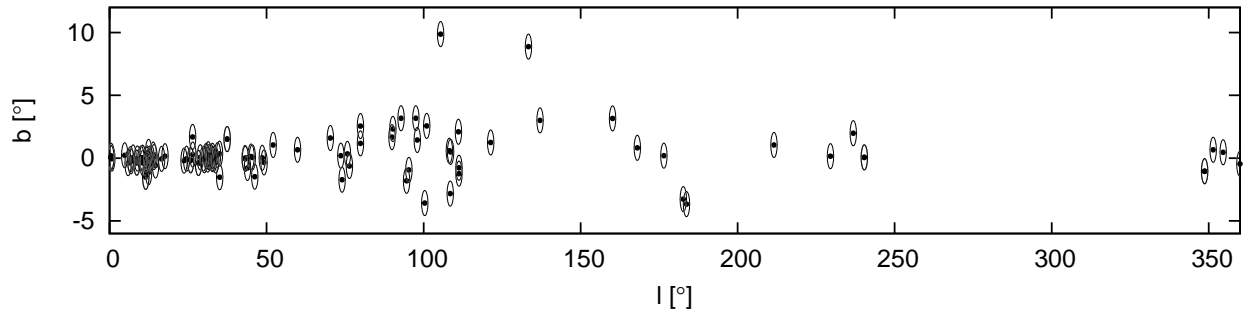
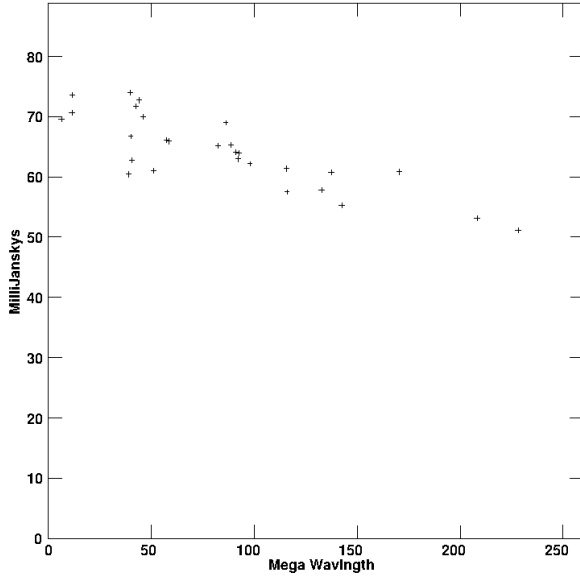
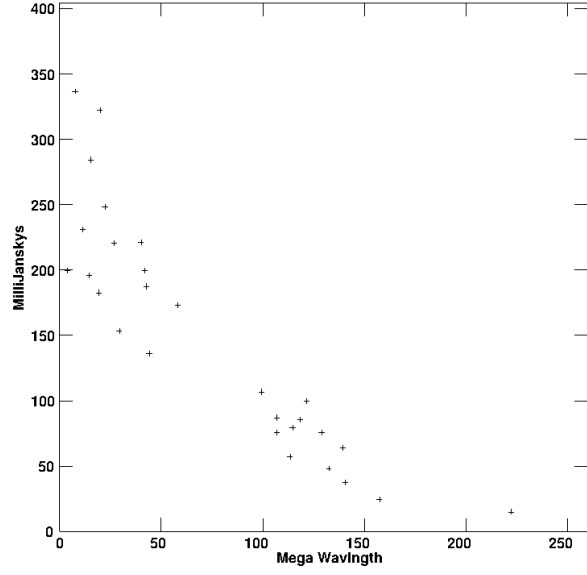


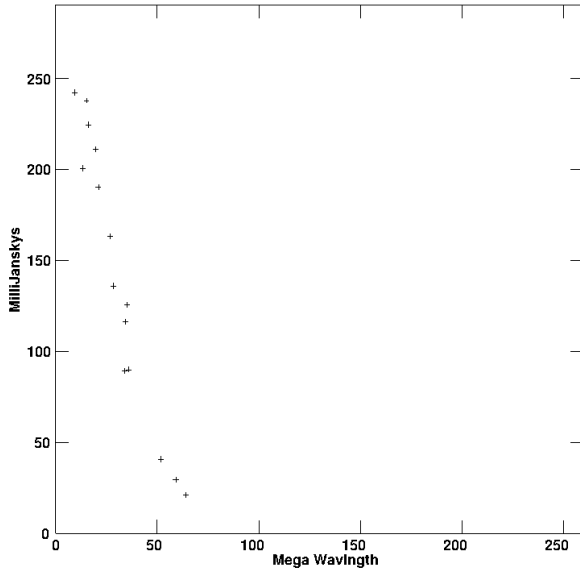
Fig. 1.—: Areal coverage of the survey with Galactic longitude l and Galactic latitude b . The black dots mark the positions of the target maser sources, the black ellipses show the circular area on the sky over which radio point sources were selected as candidate calibrator sources.



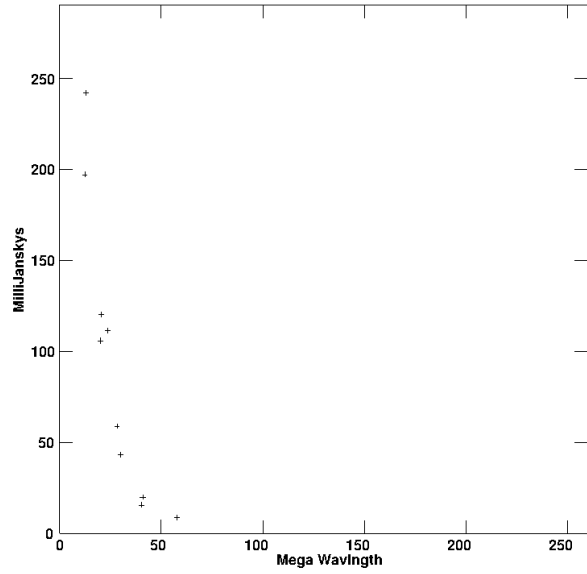
(a) J0256+6827 - Grade A source



(b) J1825-1718 - Grade B source



(c) J1751-2523 - Grade C source



(d) J1758-2343 - Grade D source

Fig. 2.—: Examples of the visibility amplitude versus baseline length plots for the four different compactness grades.

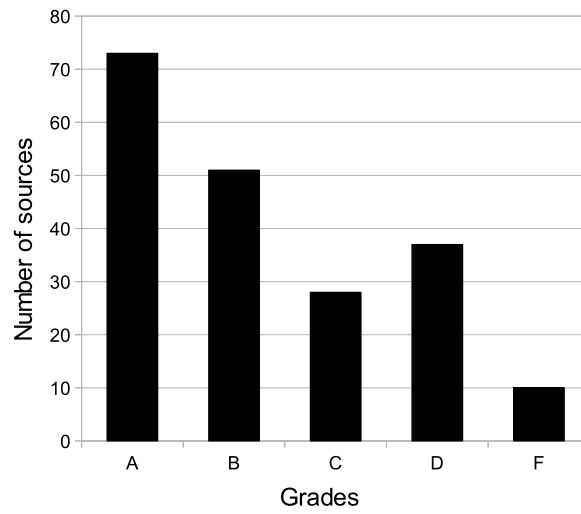


Fig. 3.—: Histogram of the distribution of sources by compactness grade.

Table 1:: Results of the position error analysis of the detected sources.

Grade	No. calibrators with $\sigma_{R.A.cos(Dec.)} < 50$ mas	$\sigma_{R.A.cos(Dec.)}$ [mas]	No. Calibrators with $\sigma_{Dec.} < 50$ mas	$\sigma_{Dec.}$ [mas]
A	23	1.60	23	2.68
B	13	2.22	13	5.07
C	13	8.64	13	11.89
D	11	11.42	11	13.54

Note. — Column 1 gives the compactness grade described in the text. Columns 2 and 4 give the number of calibrators (per grade) with position standard deviations smaller than 50 mas. Column 3 and 5 contain the empirically estimated uncertainties in Right Ascension and Declination for each grade.

Table 2. Detected sources

Name	R.A. (J2000) (hh mn ss.sssss)	Dec. (J2000) (dd " ''' .''''''')	1 σ -Unc R.A. cos(Dec.) (mas)	1 σ -Unc Dec. (mas)	Grade	Flux (Jy)	No. Obs
J0012+6551	00 12 37.67279	+65 51 10.8236	12.1	14.1	D	0.20	1
J0035+6130	00 35 25.31071	+61 30 30.7637	3.4	4.0	A	0.23	1
J0037+6236	00 37 04.33092	+62 36 33.3045	4.6	6.5	B	0.25	1
J0244+6228	02 44 57.69662	+62 28 06.5172	3.7	5.9	B	2.00	1
J0248+6214	02 48 58.89198	+62 14 09.6783	4.6	6.5	B	0.10	1
J0251+6824	02 51 45.79153	+68 24 01.7686	5.2	5.7	A	0.06	1
J0256+6827	02 56 10.82729	+68 27 51.0042	5.2	5.7	A	0.07	1
J0304+6821	03 04 22.00321	+68 21 37.4748	10.1	10.4	A	0.60	1
J0306+6243	03 06 42.65955	+62 43 02.0244	3.4	4.0	A	0.40	1
J0308+6955	03 08 27.81517	+69 55 58.9545	10.2	11.2	B	0.07	1
J0455+4653	04 55 53.20678	+46 53 30.2520	9.3	10.3	B	0.05	1
J0455+4803	04 55 07.17204	+48 03 47.3791	3.7	5.9	B	0.07	1
J0502+4729	05 02 22.33186	+47 29 12.0753	8.2	8.4	A	0.06	1
J0507+4645	05 07 23.65891	+46 45 42.3372	4.3	4.8	A	0.30	1
J0507+4720	05 07 20.43482	+47 20 36.3146	5.2	5.7	A	0.08	1
J0509+3951	05 09 48.81719	+39 51 54.6176	7.2	7.5	A	0.25	1
J0512+4041	05 12 52.54295	+40 41 43.6188	3.4	4.0	A	1.00	1
J0514+4025	05 14 02.81508	+40 25 24.0477	10.5	13.3	C	0.08	1
J0523+3926	05 23 51.23640	+39 26 57.7358	3.7	5.9	B	0.06	1
J0529+3209	05 29 28.21154	+32 09 46.9452	5.2	5.7	A	0.08	1

Table 2—Continued

Name	R.A. (J2000) (hh mn ss.sssss)	Dec. (J2000) (dd " ''' .''''''')	1σ -Unc R.A. cos(Dec.) (mas)	1σ -Unc Dec. (mas)	Grade	Flux (Jy)	No. Obs
J0535+3249	05 35 52.08521	+32 49 17.3790	14.1	14.3	A	0.05	1
J0539+3308	05 39 09.67217	+33 08 15.4957	3.7	5.9	B	0.06	1
J0540+2507	05 40 14.34318	+25 07 55.3565	3.3	3.7	A	0.09	2
J0541+3126	05 41 35.23810	+31 26 44.2135	21.1	21.6	B	0.05	1
J0541+3301	05 41 49.43590	+33 01 31.8900	7.2	7.5	A	0.08	1
J0545+3217	05 45 16.48160	+32 17 27.0506	5.2	5.7	A	0.07	1
J0549+3054	05 49 54.18174	+30 54 47.5885	6.2	6.6	A	0.08	1
J0550+2326	05 50 47.39145	+23 26 48.1628	6.2	6.6	A	0.26	1
J0557+2413	05 57 04.71415	+24 13 55.2844	6.2	6.6	A	1.00	1
J0603+2159	06 03 51.55708	+21 59 37.6982	3.7	5.9	B	0.08	1
J0607+2129	06 07 59.56570	+21 29 43.7200	3.7	5.9	B	0.01	1
J0607+2218	06 07 17.43600	+22 18 19.0800	3.7	5.9	B	0.01	1
J0608+2229	06 08 34.31090	+22 29 42.9810	3.7	5.9	B	0.06	1
J0649+0008	06 49 16.33743	+00 08 56.0797	3.4	4.0	A	0.13	1
J0650+0358	06 50 38.13429	+03 58 08.4420	3.4	4.0	A	0.15	1
J0656+0315	06 56 59.18022	+03 15 53.4395	4.6	6.5	B	0.05	1
J0657+0224	06 57 12.36716	+02 24 32.7362	3.4	4.0	A	0.09	1
J0703−0051	07 03 19.08675	−00 51 03.1574	3.4	4.0	A	0.50	1
J0721−1530	07 21 13.49140	−15 30 41.0088	4.3	4.8	A	0.15	1
J0721−1630	07 21 49.13771	−16 30 19.7464	6.2	6.6	A	0.12	1

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " "" .''''''')	(mas)	(mas)		(Jy)	
J0724–1545	07 24 59.00632	–15 45 29.3698	8.2	8.4	A	0.08	1
J0729–1320	07 29 17.81773	–13 20 02.2600	3.4	4.0	A	0.15	1
J0735–1735	07 35 45.81270	–17 35 48.5023	3.4	5.0	B	0.29	2
J0738–2403	07 38 09.99020	–24 03 56.3766	6.2	6.6	A	0.07	1
J0739–2301	07 39 24.99814	–23 01 31.8848	4.3	4.8	A	0.08	1
J0740–2444	07 40 14.71735	–24 44 36.6991	4.6	6.5	B	0.40	1
J0741–1937	07 41 52.78735	–19 37 34.8280	3.4	4.0	A	0.06	1
J0742–2043	07 42 32.10076	–20 43 41.2244	21.8	23.3	C	0.07	1
J0745–1828	07 45 19.43909	–18 28 24.7985	3.4	4.0	A	0.08	1
J0745–2451	07 45 10.26453	–24 51 43.7704	4.3	4.8	A	0.60	1
J0749–2344	07 49 51.77926	–23 44 48.7882	3.4	4.0	A	0.12	1
J0750–2451	07 50 00.40201	–24 51 36.6085	3.4	4.0	A	0.09	1
J1712–3514	17 12 05.13526	–35 14 34.1834	23.0	24.2	D	0.09	1
J1712–3736	17 12 38.79641	–37 36 46.7341	13.2	15.5	C	0.18	1
J1717–3342*	17 17 36.03045	–33 42 08.7942	7.8	9.6	D	1.40	2
J1717–3948	17 17 38.59784	–39 48 52.5572	18.9	20.2	D	0.15	1
J1719–3354	17 19 34.35417	–33 54 48.8743	1000.1	1000.1	D	0.08	1
J1723–3936	17 23 32.18591	–39 36 41.9943	11.8	13.9	D	0.09	1
J1733–3722*	17 33 15.19300	–37 22 32.3955	2.4	2.8	A	2.00	2
J1743–3058	17 43 17.88572	–30 58 18.6690	23.0	24.2	D	0.14	1

Table 2—Continued

Name	R.A. (J2000) (hh mn ss.sssss)	Dec. (J2000) (dd " ''' .''''''''')	1σ -Unc R.A. cos(Dec.) (mas)	1σ -Unc Dec. (mas)	Grade	Flux (Jy)	No. Obs
J1751–1950	17 51 41.34380	–19 50 47.5060	2.5	3.3	B	0.08	2
J1751–2523	17 51 51.26230	–25 24 00.0730	13.2	15.5	C	0.23	1
J1751–2524*	17 51 51.26204	–25 24 00.0588	10.8	12.6	C	0.25	2
J1752–2956	17 52 33.10790	–29 56 44.8983	18.2	19.9	C	0.07	1
J1752–3001	17 52 30.95041	–30 01 06.6526	15.2	15.8	B	0.14	1
J1755–2232*	17 55 26.28462	–22 32 10.6128	5.6	6.5	C	0.25	4
J1758–2343	17 58 23.01669	–23 43 12.1257	7.7	8.9	D	0.25	3
J1800–2107	18 00 44.51594	–21 07 33.7637	170.4	170.5	D	0.05	1
J1801–2214	18 01 43.54953	–22 14 28.8094	10.8	11.5	D	0.10	4
J1805–2512	18 05 23.54818	–25 12 38.7469	9.1	12.3	C	0.08	1
J1807–2506*	18 07 40.68757	–25 06 25.9440	4.0	5.2	A	0.23	3
J1808–1822	18 08 55.51552	–18 22 53.3897	3.9	4.8	C	0.08	7
J1809–1520	18 09 10.20936	–15 20 09.6991	3.4	4.0	A	0.07	1
J1809–1546	18 09 09.25000	–15 46 53.8000	...	...	F	...	1
J1810–1626	18 10 39.85118	–16 26 52.9225	5.6	6.9	C	0.08	5
J1811–2055	18 11 06.79427	–20 55 03.2781	7.8	8.9	D	0.15	4
J1813–2015	18 13 16.87269	–20 15 44.0791	10.7	11.9	D	0.05	2
J1815–1836	18 15 30.46000	–18 36 14.0000	...	...	F	...	1
J1818–1705	18 18 02.90348	–17 05 40.8859	9.0	10.1	D	0.16	3
J1819–2036	18 19 36.89582	–20 36 31.5519	8.6	10.4	D	0.09	2

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " "" .''''''')	(mas)	(mas)		(Jy)	
J1821–0502*	18 21 11.80930	–05 02 20.0900	6.4	7.9	B	0.20	1
J1821–1224	18 21 23.27826	–12 24 12.9142	10.5	13.3	C	0.04	1
J1821–2110	18 21 05.46937	–21 10 45.2453	4.2	5.8	C	0.12	2
J1825–0737*	18 25 37.60958	–07 37 30.0129	2.5	3.3	B	0.08	2
J1825–1551	18 25 11.72184	–15 51 34.4066	13.2	15.5	C	0.08	1
J1825–1718*	18 25 36.53225	–17 18 49.8474	1.3	2.1	B	0.30	8
J1827–0405*	18 27 45.04040	–04 05 44.5800	3.7	5.9	B	0.13	1
J1828–0530*	18 28 40.15371	–05 30 50.8918	9.1	12.3	C	0.07	1
J1828–0912	18 28 56.02434	–09 12 31.1181	15.9	17.4	D	0.07	1
J1832–0610	18 32 42.23000	–06 10 26.5000	...	...	F	...	1
J1832–1035	18 32 20.83656	–10 35 11.2006	15.2	16.8	D	...	1
J1832–2039*	18 32 11.04646	–20 39 48.1974	2.5	3.3	B	0.50	2
J1833–0323	18 33 23.90553	–03 23 31.4656	6.4	7.9	B	0.12	1
J1833–0855	18 33 19.58200	–08 55 27.2100	15.2	16.8	D	...	1
J1834–0301*	18 34 14.07459	–03 01 19.6268	1.6	2.5	B	0.20	7
J1837–0653	18 37 58.03336	–06 53 31.2470	9.8	11.1	D	0.07	2
J1841–0348	18 41 27.31540	–03 48 44.3323	7.5	8.5	D	0.10	5
J1846–0003	18 46 03.78257	–00 03 38.2834	8.0	9.7	C	0.10	3
J1846–0651*	18 46 06.30024	–06 51 27.7472	2.9	4.3	B	0.11	2
J1847–0004	18 47 04.96160	–00 04 47.2000	20.1	21.0	D	0.05	2

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " "" .''''''''')	(mas)	(mas)		(Jy)	
J1848+0138	18 48 21.81035	+01 38 26.6322	3.7	5.9	B	0.12	1
J1849+0349	18 49 29.17000	+03 49 55.0000	...	...	F	...	1
J1851+0035	18 51 46.72295	+00 35 32.3649	5.9	6.9	D	0.07	4
J1852+0308	18 52 37.01000	+03 08 38.9000	...	...	F	...	1
J1853–0010	18 53 10.26917	–00 10 50.7398	9.3	10.7	D	0.07	3
J1853–0048	18 53 41.98921	–00 48 54.3307	5.4	7.2	C	0.08	3
J1854+0542	18 54 36.12843	+05 42 59.3068	9.5	12.5	C	0.10	1
J1855+0215	18 55 00.11300	+02 15 41.1000	100.7	100.9	D	0.03	1
J1855+0251*	18 55 35.43646	+02 51 19.5629	2.4	3.8	C	0.12	4
J1856+0610*	18 56 31.83900	+06 10 16.7678	3.5	5.3	C	0.25	2
J1857+0051	18 57 49.55000	+00 51 19.2000	...	...	F	...	1
J1857–0048	18 57 51.35860	–00 48 21.9496	3.4	4.0	A	0.11	1
J1858+0313	18 58 02.35272	+03 13 16.3116	12.1	13.3	D	0.70	2
J1900+0003	19 00 17.57016	+00 03 55.9078	13.4	15.2	D	0.07	1
J1900+0303	19 00 33.59944	+03 03 46.0646	11.3	12.9	D	0.14	2
J1900–0009	19 00 49.56848	–00 09 15.3823	50.7	51.4	C	0.05	1
J1903+0145	19 03 53.06326	+01 45 26.3108	3.2	3.8	B	0.18	2
J1904+0110	19 04 26.39738	+01 10 36.7078	3.2	3.8	B	0.12	2
J1905+0952	19 05 39.89889	+09 52 08.4071	1.8	2.1	A	0.25	4
J1906+0139	19 06 12.96214	+01 39 13.6688	15.2	16.8	D	0.10	1

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " ''' .''''''''')	(mas)	(mas)		(Jy)	
J1907+0127	19 07 11.99613	+01 27 08.9644	3.0	3.6	B	0.25	3
J1907+0907	19 07 41.96336	+09 07 12.3968	3.3	4.6	B	0.25	2
J1908+1201	19 08 40.32064	+12 01 58.8609	3.4	4.0	A	0.11	1
J1911+1611	19 11 58.25738	+16 11 46.8600	3.4	4.0	A	0.50	1
J1913+0932	19 13 24.02539	+09 32 45.3791	10.0	12.9	C	0.16	1
J1913+1307	19 13 14.00638	+13 07 47.3307	3.4	4.0	A	0.08	1
J1917+1405	19 17 18.06412	+14 05 09.7675	3.3	3.8	B	0.12	2
J1921+1625	19 21 57.38244	+16 25 01.9231	3.4	4.0	A	0.19	1
J1922+0841*	19 22 18.63360	+08 41 57.3780	5.2	5.7	A	0.10	1
J1922+1504	19 22 33.27275	+15 04 47.5388	9.1	12.3	D	0.08	2
J1922+1530	19 22 34.69942	+15 30 10.0340	6.4	8.5	C	0.40	3
J1924+1540	19 24 39.45589	+15 40 43.9380	2.3	2.8	B	0.50	3
J1925+1227*	19 25 40.81708	+12 27 38.0856	1.7	2.0	A	0.14	5
J1927+1847	19 27 32.31207	+18 47 07.9048	3.4	4.0	A	0.07	1
J1928+1859	19 28 42.71875	+18 59 24.5627	5.5	7.1	B	0.07	1
J1930+1532	19 30 52.76690	+15 32 34.4285	3.4	4.0	A	0.45	1
J1934+1043*	19 34 35.02560	+10 43 40.3660	3.4	4.0	A	0.08	1
J1936+2246	19 36 29.30467	+22 46 25.8540	3.4	4.0	A	0.08	1
J1936+2357	19 36 00.92503	+23 57 31.9722	3.4	4.0	A	0.20	1
J1938+2348	19 38 45.60688	+23 48 15.7092	15.2	16.8	D	0.06	1

Table 2—Continued

Name	R.A. (J2000) (hh mn ss.ssssss)	Dec. (J2000) (dd " ''' .''''''')	1σ -Unc R.A. cos(Dec.) (mas)	1σ -Unc Dec. (mas)	Grade	Flux (Jy)	No. Obs
J1941+2307	19 41 55.11140	+23 07 56.5250	3.7	5.9	B	0.01	1
J1946+2255	19 46 22.29846	+22 55 24.6282	8.3	9.5	B	0.08	1
J1946+2300	19 46 06.25140	+23 00 04.4145	3.7	5.9	B	0.07	1
J1946+2418	19 46 19.96067	+24 18 56.9093	50.0	50.3	B	0.06	1
J1955+3233	19 55 56.35092	+32 33 04.5060	11.8	14.3	C	0.07	1
J1957+3216	19 57 43.00353	+32 16 33.5832	3.4	4.0	A	0.07	1
J1957+3338	19 57 40.54974	+33 38 27.9429	5.2	5.7	A	0.16	1
J1957+3427	19 57 34.44939	+34 27 54.6774	100.7	100.9	D	0.05	1
J2001+3216	20 01 16.77409	+32 16 46.9435	4.3	4.8	A	0.06	1
J2001+3323	20 01 42.20694	+33 23 44.7461	10.5	13.3	C	0.30	1
J2007+4029	20 07 44.94494	+40 29 48.6009	3.5	5.2	B	3.50	2
J2009+3543	20 09 57.63785	+35 43 18.0079	11.8	14.3	C	0.33	1
J2010+3322	20 10 49.72256	+33 22 13.8074	13.2	15.5	C	0.80	1
J2015+3410	20 15 28.83206	+34 10 39.4175	3.7	5.9	B	0.40	1
J2015+3710	20 15 28.72950	+37 10 59.5179	2.4	2.8	A	2.40	2
J2016+3600	20 16 45.61840	+36 00 33.3774	3.7	5.9	B	0.16	1
J2018+3812	20 18 42.84963	+38 12 41.3396	12.1	14.1	D	0.08	1
J2018+3851	20 18 31.02410	+38 51 19.3854	3.7	5.9	B	0.33	1
J2020+4057	20 20 36.17955	+40 57 53.0792	19.7	21.0	D	0.10	1
J2025+3343	20 25 10.84328	+33 43 00.1955	12.2	13.0	B	4.50	1

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " "" .""""")	(mas)	(mas)		(Jy)	
J2025+4335	20 25 18.96000	+43 35 24.0000	...	...	F	...	1
J2027+3612	20 27 22.15431	+36 12 14.0702	10.5	12.0	D	0.12	2
J2030+3700	20 30 31.26724	+37 00 36.0379	12.5	14.4	D	0.20	1
J2032+4057	20 32 25.77049	+40 57 27.9154	10.7	12.2	D	0.10	2
J2033+4000	20 33 03.66147	+40 00 24.3573	11.8	13.9	D	0.09	1
J2038+5119	20 38 37.03480	+51 19 12.6592	3.1	3.6	A	1.80	2
J2056+4940	20 56 42.73987	+49 40 06.6010	3.4	3.9	A	0.09	2
J2059+4851	20 59 57.87249	+48 51 12.7002	4.3	4.8	A	0.10	1
J2100+5331	21 00 56.33534	+53 31 33.1413	3.7	5.9	B	0.09	1
J2102+4702*	21 02 17.05620	+47 02 16.2530	3.4	4.0	A	0.17	1
J2105+5356	21 05 12.79000	+53 56 09.4000	...	...	F	...	1
J2114+4953	21 14 15.03646	+49 53 40.9540	4.0	4.4	A	0.12	2
J2117+5431*	21 17 56.48434	+54 31 32.5036	2.4	2.8	A	0.25	2
J2123+5452	21 23 46.83487	+54 52 43.4884	4.3	4.8	A	0.09	1
J2123+5500*	21 23 05.31345	+55 00 27.3253	2.4	2.8	A	0.25	2
J2125+6423*	21 25 27.44700	+64 23 39.3550	3.4	4.0	A	0.35	1
J2127+5528	21 27 32.27527	+55 28 33.9771	9.1	12.3	C	0.09	1
J2131+5214	21 31 58.22000	+52 14 15.9000	...	...	F	...	1
J2137+5101	21 37 00.98625	+51 01 36.1292	2.4	2.8	A	0.35	2
J2139+5300	21 39 53.62438	+53 00 16.5993	3.7	5.9	B	0.12	1

Table 2—Continued

Name	R.A.	Dec.	1 σ -Unc	1 σ -Unc	Grade	Flux	No.
	(J2000)	(J2000)	R.A. cos(Dec.)	Dec.			Obs
	(hh mn ss.sssss)	(dd " "'.'''''''')	(mas)	(mas)		(Jy)	
J2139+5540	21 39 32.61754	+55 40 31.7711	12.9	14.8	D	0.05	1
J2145+5147	21 45 07.66657	+51 47 02.2430	2.5	3.3	B	0.06	2
J2148+6107	21 48 16.04239	+61 07 05.7966	3.7	5.9	B	0.60	1
J2150+5103	21 50 14.26619	+51 03 32.2638	2.4	2.8	A	0.14	2
J2159+6606	21 59 24.68626	+66 06 52.2906	3.4	4.0	A	0.18	1
J2203+6750*	22 03 12.62260	+67 50 47.6730	3.4	4.0	A	0.22	1
J2209+5158*	22 09 21.48690	+51 58 01.8330	3.4	4.0	A	0.18	1
J2214+5250	22 14 55.76000	+52 50 58.2000	...	...	F	...	1
J2217+5202	22 17 54.46074	+52 02 51.3698	4.3	4.8	A	0.06	1
J2225+5120	22 25 25.39414	+51 20 45.7403	20.1	20.6	B	0.08	1
J2243+6055	22 43 00.81457	+60 55 44.2156	3.1	3.7	B	0.06	2
J2250+5550	22 50 42.85149	+55 50 14.5730	9.1	9.4	A	0.35	1
J2254+6209	22 54 25.29266	+62 09 38.7227	2.4	3.6	B	0.08	4
J2257+5720	22 57 22.04611	+57 20 30.1966	11.1	11.3	A	0.15	1
J2258+5719	22 58 57.94146	+57 19 06.4599	6.8	7.0	A	0.18	2
J2301+5706	23 01 26.62714	+57 06 25.4987	10.1	10.4	A	0.12	1
J2302+6405	23 02 41.31514	+64 05 52.8506	3.0	4.1	B	0.12	2
J2314+5813	23 14 19.08325	+58 13 47.6474	9.1	12.3	C	0.07	1
J2339+6010*	23 39 21.12514	+60 10 11.8504	2.4	2.8	A	0.30	2

Note. — Columns 1 through 3 give the source name and its Right Ascension (R.A.) and Declination (Dec.). The asteriks mark sources for which the ICRF2 source position was averaged in with the source position. Weighted means are given for those calibrators that were observed more than once. Columns 4 and 5 give the coordinate uncertainties, determined from the quadrature sum of the formal fitting errors and the error floors for the appropriate compactness grade. For the grade F sources, the coordinates from the NVSS catalog were used. Column 6 and 7 contain the compactness grades, A through F, as well as the source fluxes. Column 8 gives the number of observations for each source.

Table 3:: Undetected sources.

Name	R.A. (J2000)	Dec. (J2000)	Unc	Flux
	(hh mm ss.ss)	(dd " '''."')	(")	Jy
J0022+6351	00 22 52.31	+63 51 21.8	0.7	0.030
J0023+6349	00 23 25.39	+63 49 45.5	0.9	0.022
J0027+6425	00 27 34.96	+64 25 55.1	0.7	0.041
J0028+6227	00 28 27.82	+62 27 12.8	0.6	0.148
J0028+6345	00 28 40.03	+63 45 59.9	0.6	0.074
J0029+6303	00 29 23.38	+63 03 35.5	0.6	0.096
J0029+6358	00 29 45.11	+63 58 41.5	0.6	2.992
J0031+6322	00 31 32.49	+63 22 08.5	0.6	0.108
J0032+6301	00 32 11.97	+63 01 00.7	0.7	0.041
J0033+6428	00 33 38.87	+64 28 45.4	0.6	0.107

Note. — The coordinates, coordinate uncertainties, and the fluxes are extracted from the CORNISH and NVSS point source catalogs. The entire table is available in the online version.